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Calculational and Experimental Investigations into the Effects of the Scatterer and Matrix on Phononic Crystals Properties

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Abstract

Three-dimensional phononic crystals based on the locally resonant structure were fabricated in this work. The effects of the physical properties of the scatterer and matrix on the acoustic absorption coefficient (AAC) were investigated via calculational and experimental methods simultaneously. The consistency of calculational and experimental results was examined. Two kinds of backing of standing wave tube, air and steel-air backing, were used to validate the changing discipline of AAC. The results suggested that the location, extension and intensity of resonant peak had the close relationship with the modulus and thickness of the scatterer's coating layer, and the modulus of matrix. The type of backing also influenced the AAC of phononic crystals.

Keywords: acoustical materials; phononic crystal; locally resonant; acoustic absorption coefficient; calculation

1. Introduction

Since phononic crystal was proposed by Kushwaha in 1990's [1], it has triggered many exciting investigations [2,3]. The phononic crystal is a kind of periodic structure composite with elastic wave band

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gap which determined the acoustic property, and the generation theory of phononic band gap includes Bragg scattering [2] and locally resonant [3]. Based on the locally resonant structure, the existence of

Table 1. The mechanical properties of different silicon rubber layers

Samples	Matrix Modulus(MPa)	Coating Layer Modulus (MPa)	Coating Layer Thickness(mm)
1-1	10	0.22	0.5
1-2	10	0.46	0.5
1-3	10	098	0.5
2-1	10	0.98	1.5
2-2	20	0.22	0.5

spectral gaps at extremely low frequency was demonstrated [3], and thence phononic crystal becomes an important low-frequency sound-absorbing material.

Generally, phononic crystal contains at least two phase elastic media, continuous phase and discontinuous phase, which called matrix and scatterer, respectively. Both the physical properties of matrix and scatterer play a critical role in the propagation and the absorption of sonic wave. These properties affect some crucial parameters of acoustic absorption, such as resonant peak's location, extension and intensity [4,5]. A lot of work focused on the theoretical calculation and numerical simulation [6-9], but the experiments carried out by relatively small scientists [10,11]. In this work, the 3D phononic crystals were fabricated, and the effects of matrix and scatterer on the acoustic absorption coefficient (AAC) were researched via computational and experimental methods simultaneously. The effectiveness and limitation of calculation method were examined, and the experimental results will be beneficial to the theoretical investigation and improvement of performance.

2. Experiments

A styrene-butadiene rubber was chosen as the matrix, and the modulus was adjusted via changing the rubber components. The steel balls coated by silicon rubber were used as the scatters. Two kinds of silicon rubber, 1# and 2#, were used as coating layers in this work; and $CaCO_3$ was mixed with 2# to obtain the coating layer with higher modulus. The detail information of the samples was shown in Table 1. The silicon rubbers were mixed with the curing agent firstly, and coated on steel balls; the locally resonant units were filled in the matrix with a periodic structure. The mechanical properties of materials were performed with tensile test machine; the acoustic absorption coefficients were characterized in standing wave tube at 10^{o}C, and the frequency ranged from 500 to 5000Hz, and air and steel-air were used as backing respectively. At the same time, AAC of phononic crystals were calculated with computer.

3. Results and Discussion

Firstly, the effect of scatterer's property on AAC was investigated. The AAC curves for phononic crystals with different coating layer's modulus were obtained via simulation calculation, and four modului were employed. All AAC curves have several resonant absorption peaks, which correspond to the different elastic wave band gaps (Figure 1). With the increase of coating layer's modulus, the lower acoustic absorption peak shifted to the high frequency, and the peak intensity augmented simultaneously. It can be explained by the following equation [12,13]:

$$f = \frac{1}{\pi}\sqrt{\frac{ES}{ML}} \tag{1}$$

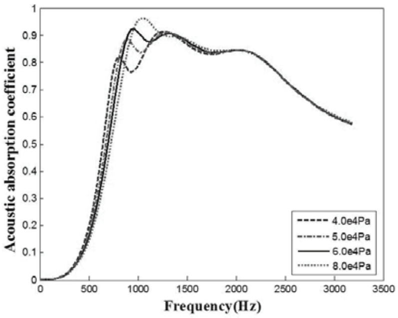

Figure 1. Calculational results of effect of coating layer's modulus on AAC.

which f is the resonant frequency, E is the modulus of elastic coating layer, S is the stressed area of scatterer, L is the thickness of coating layer, and M is the mass of the scatterer. The equation (1) shows that the increasing of modulus will result in the elevation of the resonant frequency. In addition, the stressed area (i.e. the size of scatterer), the mass of scatterer, and the thickness of coating layer are important factors influencing resonant frequency.

To examine the results of computation, three silicon rubber coating layers with different modulus were prepared, and the information of coating layers was showed in Table 1. Furthermore, the AAC measurements were carried based on air backing and steel-air backing respectively, in order to validate the changing discipline of AAC. Within the measurement scale, sample 1-1 with lowest modulus presents two peaks corresponding to the phononic band gaps, and the others only have one absorption peak obtained with air backing (Fig 2A). Moreover the first resonant peak of AAC shifts to higher frequency, and the peak intensity increases slightly, which is consistent with the calculating result. The results based on the steel-air backing don't present distinct trend (Figure 2B). Comparing with sample 1-1, the resonant peaks of 1-2 and 1-3 shift to higher frequency, but there is no obvious difference between 1-2 and 1-3. Overall, the phononic crystal shows the broader band gap and higher intensity when using steel-air backing than air backing.

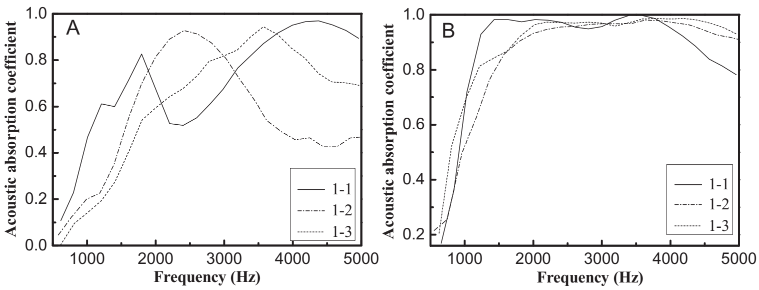

Figure 2. Experimental results of effect of coating layer's modulus on AAC: A) air backing; B) steel-air backing.

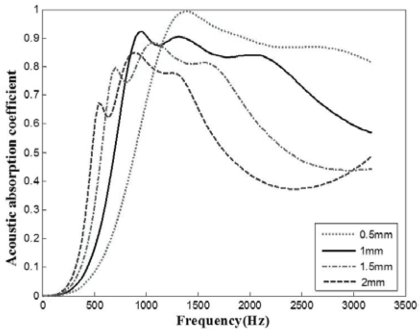

Figure 3. Calculational results of effect of coating layer's thickness on AAC.

In addition, equation (1) indicates the thickness of coating layer, L, influence the resonant frequency f, so the effect of thickness was also investigated via calculation and experiment. The calculating results suggested that the first absorption peak shifted to lower frequency, and the intensity gradually weakened with the increasing of coating layer's thickness (Figure 3). The result is consistent with equation (1). The experimental data of phononic crystal with 0.5mm and 1.5mm thickness coating layers were compared in Figure 4, and the measurements were carried with air and steel-air backing as well. Both the resonant frequency based on different backings shows the similar trend to the calculating results. However, the peak intensity does not change obviously when using air backing, and the intensity between 2000-5000Hz weakens when using steel-air backing.

The property of matrix is also the critical factor influencing the AAC of phononic crystal. The effect of matrix modulus on AAC via calculation is shown in Figure 5, the AAC curves showed a clear regularity. The resonant peak shifts to higher frequency with the increase of matrix's modulus. The experimental data presented the similar trend with computation results when using air backing, and there is no distinct difference when using steel-air backing (Figure 6). Similar with above data, the better acoustic absorption property was achieved when using steel-air backing.

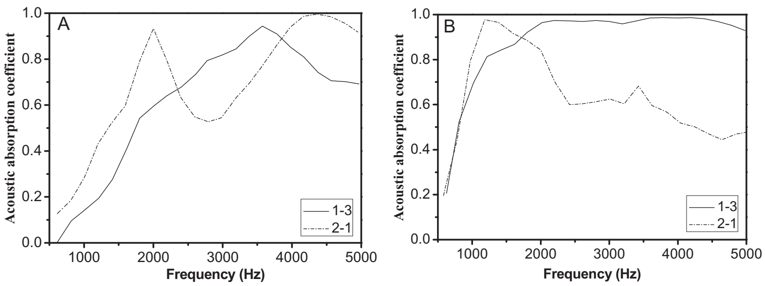

Figure 4. Experimental results of effect of coating layer's thickness on AAC: A) air backing; B) steel-air backing.

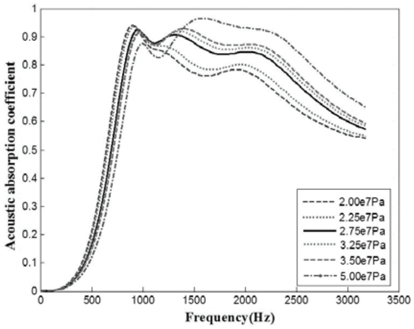

Figure 5. Calculational results of effect of matrix’s modulus on AAC.

4. Conclusions

The acoustic absorption coefficient of phononic crystal obtained via experimental method can better match the calculating results, especially when using air backing. When using steel-air backing, the phononic crystals possess broader band gap and higher acoustic absorption coefficient, which means the better sound absorption property can be achieved with steel-air backing. With the increasing of coating layer’s modulus or the decreasing of the coating layer’s thickness, the resonant absorption peaks of phononic crystals shift to higher frequency, and the intensities of first absorption peaks strengthen. The increasing of matrix’s modulus causes the shifting of absorption peak to higher frequency as well. This work validates the effectiveness and limitation of calculation method, and provides an experimental basis for the theoretical research of phononic crystal materials.

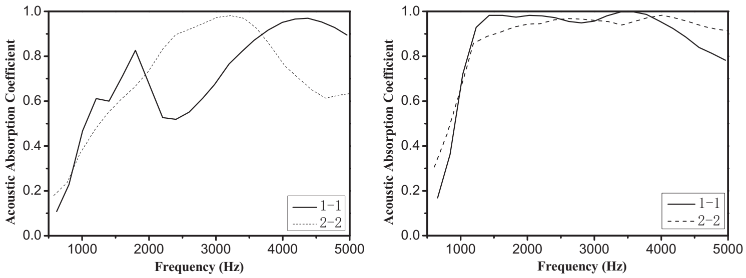

Figure 6. Experimental results of effect of matrix’s modulus on AAC: A) air backing; B) steel-air backing.

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